# Geomorphic and Pedogenic Processes Operative in Soils of a Hillslope in the Unglaciated Region of Ohio[1]

E. A. AMBA, N. E. SMECK, G. F. HALL, AND J. M. BIGHAM, Department of Agronomy, The Ohio State University, Columbus, OH 43210, and The Ohio Agricultural Research and Development Center, Wooster, OH 44619

**ABSTRACT. Parent material uniformity, weathering, and clay translocation in three soils comprising a uniform hillslope in Jefferson County were evaluated to obtain a better understanding of geomorphic and pedogenic processes operative in the unglaciated region of Ohio. Based on detailed field observations, it was hypothesized that at least three parent materials occurred in all three soils. The hypothesis was confirmed using contents and ratios of elements occurring almost exclusively in resistant minerals. The three parent materials are: 1) a surface mantle of silty colluvium (colluvium with an admixture of loess), 2) a middle layer of colluvium having a high content of coarse fragments, and 3) residuum derived from sandstone. Weathering indices indicate that all three materials are uniformly weathered along the hillslope. Both mineralogy and distribution of clay show that weathering processes tend to attenuate lithologic differences. However, clay distribution provides evidence to suggest that the soils have been subjected to alternating periods of stability and instability. Instability results in the truncation of profiles or the addition of colluvium by solifluction, depending on location within the slope profile. It is speculated that solifluction was favored by the periglacial climate associated with the Wisconsinan glacial epoch.**

**OHIO J. SCI. 90 (1): 4-12, 1990**

## INTRODUCTION

During the past decade, the Ohio Cooperative Soil Survey program, a joint effort of the Soil Conservation Service (USDA), the Division of Soil and Water Conservation (Ohio Department of Natural Resources), and the Ohio Agricultural Research and Development Center, has been concentrated in the unglaciated region of Ohio. Prior to extensive soil mapping in the unglaciated region of Ohio, the soils were generally thought to be shallow and pedologically immature because of the constant removal of weathered materials by erosion. The landscape of this region of Ohio is characterized primarily by erosional features: steep slopes, narrow ridge tops, and deeply entrenched valleys. Proximity to the continental ice sheets has superimposed some constructional elements such as valley terraces, a discontinuous loess mantle, and partial valley filling and resulted in numerous drainage reversals.

Recent mapping has supported previous investigations of Lessig (1959a, 1959b, 1959c, 1961a, 1961b, 1963, 1964), which revealed a complex association of soils ranging from Entisols and Inceptisols to Alfisols and Ultisols. Whereas residuum might be anticipated as the most common parent material, glacial outwash (Lessig 1959a, 1959b, 1959c, 1961a, 1961b), lacustrine deposits (Lessig 1963), loess (Rutledge et al. 1975a) and colluvium (Thompson et al. 1981) have also been identified and constitute the parent materials for many ground soils (Lessig 1964). The occurrence of paleosols in many soil profiles (Lessig 1959a, 1959b, 1959c, 1961a, 1961b, 1964, Thompson et al. 1981, Shipitalo et al. 1988) indicates the existence of multiple episodes of soil formation. Whereas paleosols suggest soil burial, the occurrence of stonelines (Thompson et al. 1981) indicates truncation of soils during periods of landscape instability. All evidence indicates that most soils in the unglaciated region of Ohio are not shallow and immature, but have evolved through a complex and varied pedological history from multiple parent materials.

Paleosols, stonelines, and changes in parent materials are obvious in some soils by field observation and study, but such features in other soils may be overlooked or may be impossible to detect by field morphology. In the latter case, particle size distribution, mineralogy, and elemental ratios in sand and silt fractions provide powerful tools for identifying weathering and lithologic discontinuities (Brewer 1964, Smeck and Wilding 1980). Thus, the objective of this study was to combine field and laboratory technology to evaluate weathering and parent material influences contributing to the polygenetic nature of soils comprising a representative hillslope in southeastern Ohio. Such information will aid in unraveling pedogenic pathways involved in the formation of soils occurring in the unglaciated region of Ohio.

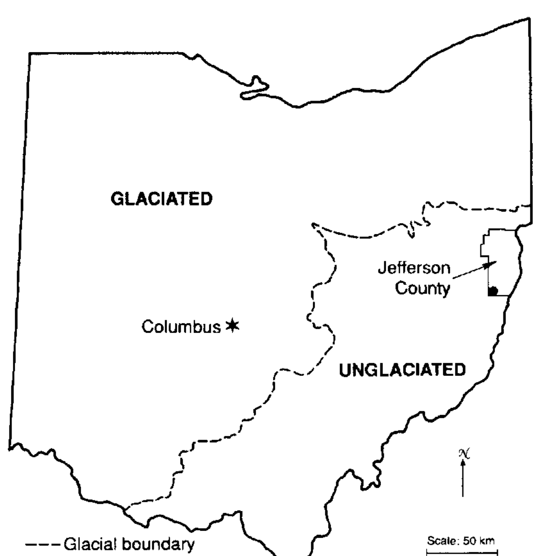

FIGURE 1. Location of study site in the unglaciated region of Ohio.

[1]Manuscript received 1 February 1989 and in revised form 25 August 1989 (#89-6).

# MATERIALS AND METHODS

## Site Selection, Location, and Characteristics

To test our ability to detect weathering and lithologic discontinuities in landscapes wherein they were not evident during mapping, the hillslope selected for study, of necessity, provided as uniform a landscape as possible. Criteria used for selection of a slope profile were uniform soils and bedrock lithology. The site which was selected is located approximately 2 km southeast of Harrisville in Sec. 34, Mount Pleasant Township, Jefferson County (Fig. 1). The hillslope exhibits classic shoulder, backslope, and footslope components. The entire site was in pasture. All soils within the slope segment studied were mapped Gilpin (fine-loamy, mixed, mesic Typic Hapludults) by USDA Soil Conservation Service soil scientists. Furthermore, preliminary random observations with a hand probe of soils on the hillslope revealed little variation in morphological soil properties. Reference to a stratigraphic column prepared by U.S. Geological Survey (USGS) geologists near the site suggested that the bedrock immediately underlying the hillslope correlated with the Waynesburg Sandstone Member of the Washington Formation (Dunkard Group). The glacial boundary is approximately 64 km north of the site (Fig. 1).

## Field Procedures and Sample Site Characteristics

Twenty observation points were located at 9 m intervals along a 180 m transect running from the crest of the hill to the toe. Elevations of these points were determined using survey equipment and USGS Well No. W-93 (352.41 m) as a benchmark. Soil cores (7.6 cm diameter) were collected to a depth of 150 cm with a truck-mounted hydraulic probe at each of the 20 transect points. Data collected by examination of cores were used to select three representative locations for more detailed sampling in the shoulder (JF-3), backslope (JF-4), and footslope (JF-5) positions. A pit was excavated with a backhoe at each of these sites and detailed soil descriptions were recorded using standard terminology (Soil Survey Staff 1984). Bulk samples were collected from each soil horizon. The slope at each sample site was 8, 24, and 18% and elevations were 374, 369, and 358 m for JF-3, JF-4, and JF-5, respectively. Correlation of elevations with the USGS data obtained on top of the hill revealed that the bedrocks at the upper two sampling sites (JF-3 and JF-4) correlate with the Waynesburg Sandstone Member, whereas the bedrock at JF-5 correlates with the underlying Uniontown Shale Member of the Monongahela Formation. The profile description of JF-5 confirms that the lower horizons extend through a Waynesburg No. 11 Coal blossom into the Uniontown Shale. Whereas profiles JF-3 and JF-4 were both well-drained, JF-5 was moderately well-drained. Classification of the soils using Soil Taxonomy (Soil Survey Staff 1975) was as follows: loamy-skeletal, mixed, mesic Typic Hapludalf for JF-3; loamy-skeletal, mixed, mesic Ultic Hapludalf for JF-4; and fine-loamy, mixed, mesic Aquic Fragiudalf for JF-5.

## Laboratory Procedures

Soil samples were dried, ground between wooden rollers, sieved to remove material > 2 mm, and thoroughly mixed. Coarse fragment content was determined by weighing the > 2 mm fraction. All subsequent analyses of the < 2 mm fraction were made in duplicate. Particle-size distribution was determined after dispersion with sodium hexametaphosphate according to the method of Kilmer and Alexander (1949). The pH of each sample was measured after equilibration with water or 0.01 M $CaCl_2$ in a 1:1 or 1:2 soil-to-solution ratio, respectively. Organic carbon content was determined by dry combustion (950° C), using a method similar to that described by Allison et al. (1965). The content of exchangeable base was determined in 1 M $NH_4OAc$ (pH 7.0) extracts by atomic absorption (Ca, Mg) or flame emission (K) spectrophotometry. Extractable acidity was measured according to the method of Peech et al. (1947). Calcite and dolomite contents were determined by a gasometric procedure (Dreimanis 1962) on samples with pH > 7.1.

Thirty-gram samples of selected horizons were separated into sand (2000 - 50 µm), silt (50 - 2 µm), and clay (< 2 µm) fractions for elemental analysis and clay mineralogy studies. Samples of the total silt fraction were pressed into pellets and analyzed by x-ray fluorescence for Ti, Zr, Ca, and K, using the methods described by Rutledge et al. (1975b). Total clay specimens were analyzed by x-ray diffraction after the following treatments: Mg saturation (air-dried and ethylene glycol-solvated) and K saturation (25° C, 350° C and 550° C heat treatments). Semi-quantitative estimates of clay mineralogy were made from the five diffractograms.

# RESULTS

## Field Studies

As indicated by the soil map and preliminary field investigations, the general morphological features of all three pedons are similar (Table 1). All three pedons have brown (10YR 4/3) Ap horizons and primarily yellowish brown (10YR 5/4, 5/5, or 5/6) or dark yellowish brown (10YR 4/4) B horizons. Textures are dominantly silt loams, particularly in the upper portion of the sola, and structures and consistencies are similar. All three pedons exhibit clay coatings on peds in the B horizons.

Detailed study of the morphology of the transect cores and sample pits suggests the occurrence of lithologic discontinuities. The strongest field evidence was the occurrence of stonelines indicative of former erosion surfaces at 81 cm in JF-4 and 69 cm in JF-5. Combining the presence of stonelines and other morphological field evidence, it was hypothesized that at least three parent materials were present in each of the pedons (indicated by Arabic numbers as the first part of the horizon designations in Tables 1 and 2; note that "1" is not used, as at least one parent material is always implied). None of the lithologic discontinuities were immediately apparent during mapping or preliminary observations; differences in materials could be detected only under close scrutiny in a pit. A soil scientist would have difficulty detecting such subtle lithologic changes during routine mapping.

The uppermost parent material is characterized as a mantle of relatively uniform thickness extending over the entire slope and having a high silt content (>50%, Table 2). Such features are characteristic of Wisconsinan loess,

TABLE 1
*Abbreviated list of morphological characteristics of soils.*

| Horizon | Depth (cm) | Field Estimated Coarse Fragments (% by volume) | Morphological Properties: Color† | Textural‡ Class | Structure* | Consistence** | Observed# Clay Films |
|---|---|---|---|---|---|---|---|
| | | | JF-3 | | | | |
| Ap1 | 0- 8 | 0 | 10YR 4/3 | sil | gr | vfr | nd |
| Ap2 | 8- 20 | 5 | 10YR 4/3 | sil | gr | fr | nd |
| BE | 20- 25 | 20 | 10YR 5/5 | grsil | pl | fr | nd |
| Bt1 | 25- 43 | 20 | 10YR 5/5 | grsil | sbk | fr | tvp |
| Bt2 | 43- 56 | 20 | 10YR 5/5 | cbl | sbk | fi | tvp |
| 2Bt3 | 56- 66 | 40 | 10YR 6/4 | vgrl | sbk | fi | mc |
| 2Bt4 | 66- 81 | 60 | 10YR 5/4 | vcbl | sbk | fi | mc |
| 2Bt5 | 81- 91 | 75 | 10YR 5/4 | ecbcl | sbk | fi | mc |
| 3Bt6 | 91-112 | 5 | 10YR 5/2 | c | abk | fi | tc |
| 3Bt7 | 112-124 | 10 | 10YR 5/2 | sic | abk | fi | tc |
| 3BC1 | 124-147 | 5 | 10YR 5/4 | sil | pl | fi | tvp |
| 3BC2 | 147-196 | 10 | 10YR 5/4 | chsil | pl | fr | nd |
| | | | JF-4 | | | | |
| Ap1 | 0- 8 | 5 | 10YR 4/3 | sil | gr | vfr | nd |
| Ap2 | 8- 18 | 10 | 10YR 4/3 | sil | gr | fr | nd |
| BE | 18- 25 | 20 | 10YR 4/4 | grsil | sbk | fr | nd |
| Bt1 | 25- 38 | 25 | 10YR 4/4 | grsil | sbk | fi | tvp |
| 2Bt2 | 38- 51 | 40 | 10YR 4/4 | vgrl | sbk | fi | tvp |
| 2Bt3 | 51- 69 | 75 | 10YR 4/4 | egrl | sbk | fi | tp |
| 2Bt4 | 69- 81 | 25 | 10YR 5/4 | grsil | sbk | fi | tvp |
| 3Bt5 | 81-107 | 10 | 10YR 5/4 | sil | sbk | fi | mc |
| 3Bt6 | 107-140 | 25 | 10YR 5/4 | chsil | sbk | fi | mc |
| 3BC | 140-179 | 60 | 2.5 Y 5/4 | vchl | pl | fi | mp |
| | | | JF-5 | | | | |
| Ap1 | 0- 8 | 5 | 10YR 4/3 | sil | gr | vfr | nd |
| Ap2 | 8- 20 | 10 | 10YR 4/3 | sil | sbk | fr | nd |
| BE | 20- 25 | 20 | 10YR 5/4 | grsil | sbk | fr | nd |
| Bt1 | 25- 36 | 30 | 10YR 5/4 | grsil | sbk | fr | tp |
| Bt2 | 36- 51 | 45 | 10YR 5/6 | vgrsil | sbk | fi | mp |
| Bt3 | 51- 69 | 25 | 10YR 5/5 | grsil | sbk | fr | mp |
| 2Btx1 | 51- 69 | 20 | 10YR 4/4 | grsil | pl | vfi & br | nd |
| 2Btx2 | 69- 86 | 40 | 2.5Y 5/4 | vgrcl | sbk | vfi & br | mp |
| 2Btx3 | 86-109 | 40 | 10YR 5/4 | vgrl | sbk | vfi & br | thc |
| 3C1 | 109-130 | 35 | 10YR 4/4 | chsil | ma | fi | nd |
| 4C2 | 130-147 | 0 | N 2/ | cl | ma | fi | nd |
| 5C3 | 147-163 | 0 | 10YR 5/4 | c | ma | fi | nd |
| 6C4 | 163-183 | 0 | 2.5Y 5/4 | sic | ma | fi | nd |
| 6C5 | 183-208 | 0 | 10YR 5/4 | sicl | ma | fi | nd |

† Munsell notations are given for colors.

‡ Textural Class Abbreviations: sil for silt loam; l for loam; cl for clay loam; c for clay; sic for silty clay; sicl for silty clay loam; coarse fragment modifiers: gr for gravelly; vgr for very gravelly; egr for extremely gravelly; cb for cobbly; vcb for very cobbly; ecb for extremely cobbly; ch for channery; vch for very channery.

* Structure Abbreviations: gr for granular; skb for sub-angular blocky; abk for angular blocky; pl for platy; ma for massive.

** Consistence Abbreviations: vfr for very friable; fr for friable; fi for firm; vfi for very firm; br for brittle.

# Clay Film Abbreviations: nd - none described; tvp - thin very patchy; tp - thin patchy; tc - thin continuous; mp - medium patchy; mc - medium continuous; thc - thick continuous.

TABLE 2
*Particle size distribution and chemical properties of soils.*

| Depth (cm) | Horizon | Coarse Frag. (% of Soil) 75-2mm | Particle Size Distribution (% of < 2000 µm) 2000-50 µm | 50-2 µm | <2 µm | pH $H_2O$ (1:1) | $CaCl_2$ (1:2) | Organic Carbon % | Exchangeable Cations C mol (+) Kg $^{-1}$ Ca | Mg | K | H | Base Sat'n % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | JF-3 | | | | | | | |
| 0- 8 | Ap1 | 12.0 | 13.8 | 61.5 | 19.7 | 5.9 | 5.6 | 2.76 | 6.7 | 1.5 | 0.89 | 8.1 | 53 |
| 8- 20 | Ap2 | 6.5 | 20.0 | 59.9 | 20.1 | 6.3 | 5.9 | 1.93 | 6.3 | 1.3 | 0.53 | 6.0 | 58 |
| 20- 25 | BE | 17.2 | 24.8 | 55.3 | 19.9 | 5.3 | 4.8 | 0.42 | 3.2 | 0.8 | 0.34 | 4.6 | 49 |
| 25- 43 | Bt1 | 17.8 | 23.4 | 54.1 | 22.5 | 4.7 | 4.2 | 0.28 | 2.3 | 0.8 | 0.24 | 7.0 | 32 |
| 43- 56 | Bt2 | 5.7 | 29.0 | 49.0 | 22.0 | 4.6 | 4.1 | 0.21 | 2.0 | 0.9 | 0.19 | 7.2 | 34 |
| 56- 66 | 2Bt3 | 32.2 | 33.3 | 47.8 | 18.9 | 4.7 | 4.2 | 0.20 | 2.9 | 1.0 | 0.17 | 6.6 | 38 |
| 66- 81 | 2Bt4 | 46.9 | 31.5 | 47.1 | 21.4 | 4.7 | 4.1 | 0.10 | 3.3 | 1.7 | 0.16 | 7.4 | 41 |
| 81- 91 | 2Bt5 | 20.1 | 40.4 | 32.5 | 27.1 | 4.7 | 4.2 | 0.13 | 4.9 | 2.9 | 0.20 | 7.3 | 52 |
| 91-112 | 3Bt6 | 10.4 | 12.1 | 37.7 | 50.2 | 4.7 | 4.3 | 0.15 | 8.7 | 5.3 | 0.31 | 6.7 | 68 |
| 112-124 | 3Bt7 | 9.9 | 10.8 | 48.8 | 40.4 | 5.8 | 5.6 | 0.24 | 8.2 | 4.6 | 0.31 | 2.3 | 85 |
| 124-147 | 3BC1 | 9.0 | 16.3 | 60.1 | 23.1 | 6.7 | 6.3 | 0.11 | 6.4 | 3.2 | 0.20 | 2.2 | 82 |
| 147-170 | 3BC2 | 18.0 | 22.8 | 56.1 | 21.1 | 6.9 | 6.5 | 0.04 | 8.3 | 3.5 | 0.20 | 2.3 | 84 |
| 170-196 | 3BC2 | 50.9 | 27.3 | 53.1 | 19.6 | 7.0 | 6.7 | 0.09 | 7.2 | 2.7 | 0.18 | 2.0 | 83 |
| | | | | | | JF-4 | | | | | | | |
| 0- 8 | Ap1 | 12.5 | 23.2 | 57.9 | 18.9 | 6.4 | 6.0 | 1.83 | 7.4 | 1.6 | 0.41 | 5.8 | 62 |
| 8- 18 | Ap2 | 5.2 | 20.2 | 68.2 | 11.6 | 7.1 | 6.4 | 1.42 | 6.8 | 1.3 | 0.30 | 3.6 | 70 |
| 18- 25 | BE | 9.4 | 24.6 | 60.9 | 14.5 | 7.3 | 6.8 | 0.92 | 6.3 | 1.2 | 0.27 | 3.1 | 71 |
| 25- 38 | Bt1 | 15.3 | 27.5 | 54.6 | 17.9 | 7.1 | 6.6 | 0.34 | 4.4 | 1.1 | 0.15 | 2.7 | 68 |
| 38- 51 | 2Bt2 | 22.4 | 33.4 | 44.5 | 17.1 | 7.0 | 6.5 | 0.26 | 4.4 | 1.2 | 0.14 | 3.0 | 66 |
| 51- 69 | 2Bt3 | 59.9 | 47.4 | 35.4 | 17.2 | 6.3 | 5.9 | 0.17 | 4.1 | 1.1 | 0.12 | 3.1 | 63 |
| 69- 81 | 2Bt4 | 25.4 | 23.8 | 55.5 | 20.7 | 5.2 | 4.7 | 0.13 | 5.2 | 1.6 | 0.17 | 6.2 | 53 |
| 81-107 | 3Bt5 | 31.1 | 12.2 | 63.7 | 24.1 | 4.8 | 4.4 | 0.11 | 5.4 | 3.2 | 0.21 | 8.1 | 52 |
| 107-140 | 3Bt6 | 35.8 | 19.6 | 57.1 | 23.3 | 4.9 | 4.5 | 0.16 | 5.3 | 4.1 | 0.20 | 8.3 | 54 |
| 140-157 | 3BC | 49.9 | 49.8 | 33.5 | 16.7 | 5.0 | 4.5 | 0.12 | 4.6 | 3.5 | 0.17 | 6.4 | 56 |
| 157-179 | 3BC | 62.6 | 14.6 | 65.0 | 20.4 | 5.1 | 4.6 | 0.13 | 5.8 | 4.8 | 0.21 | 6.2 | 64 |
| 179-203 | R* | | | | | 5.1 | 4.7 | 0.15 | 7.0 | 4.8 | 0.29 | 4.5 | 73 |
| | | | | | | JF-5 | | | | | | | |
| 0- 8 | Ap1 | 0.6 | 13.3 | 62.9 | 23.8 | 5.9 | 5.4 | 2.18 | 7.0 | 1.4 | 0.86 | 7.2 | 56 |
| 8- 20 | Ap2 | 2.8 | 14.5 | 69.8 | 15.7 | 6.3 | 5.8 | 1.20 | 5.7 | 1.2 | 0.42 | 5.4 | 58 |
| 20- 25 | BE | 3.2 | 14.1 | 62.8 | 23.1 | 6.3 | 5.8 | 0.38 | 5.3 | 1.4 | 0.22 | 4.3 | 62 |
| 25- 36 | Bt1 | 8.3 | 17.3 | 59.1 | 23.6 | 5.9 | 5.4 | 0.31 | 5.7 | 1.5 | 0.18 | 4.5 | 62 |
| 36- 51 | Bt2 | 6.0 | 18.6 | 55.2 | 26.2 | 4.9 | 4.4 | 0.28 | 4.8 | 1.3 | 0.19 | 7.2 | 47 |
| 51- 69 | Bt3 | 3.0 | 20.2 | 54.5 | 25.3 | 4.5 | 4.0 | 0.18 | 3.3 | 1.2 | 0.13 | 9.6 | 33 |
| 51- 69 | 2Btx1 | 3.9 | 24.3 | 50.9 | 24.8 | 4.4 | 3.9 | 0.17 | 3.0 | 1.4 | 0.20 | 10.7 | 30 |
| 69- 86 | 2Btx2 | 9.5 | 22.2 | 49.9 | 27.9 | 4.4 | 3.9 | 0.12 | 3.3 | 1.3 | 0.19 | 12.0 | 29 |
| 86-109 | 2Btx3 | 8.2 | 25.0 | 48.1 | 26.9 | 4.4 | 3.9 | 0.12 | 4.0 | 1.5 | 0.18 | 10.5 | 35 |
| 109-130 | 3C1 | 11.8 | 22.6 | 51.4 | 26.0 | 4.7 | 4.3 | 0.35 | 6.0 | 1.6 | 0.16 | 7.6 | 51 |
| 130-147 | 4C2 | 0 | 34.3 | 34.5 | 31.2 | 5.9 | 5.4 | 22.99 | 50.1 | 8.4 | 0.27 | 32.5 | 64 |
| 147-163 | 5C3 | 0 | 8.2 | 37.0 | 54.8 | 6.9 | 6.8 | 0.39 | 19.2 | 4.0 | 0.54 | 2.1 | 92 |
| 163-183 | 6C4** | 0 | 2.8 | 55.5 | 41.7 | 8.0 | 7.6 | | | | | | |
| 183-208 | 6C5** | 2.6 | 6.5 | 61.3 | 32.2 | 7.8 | 7.5 | | | | | | |

* In R horizon, chemical analysis determined on crushed rock.

** Calcareous horizons - 6C4 contains 14.6% calcium carbonate equivalent and 6C5 contains 4.9% calcium carbonate equivalent.

which occurs extensively in southeastern Ohio, but the inclusion of numerous coarse fragments (Tables 1 and 2) precludes referring to this material strictly as loess. In pedon JF-5, a stoneline at 69 cm separates the uppermost parent material from the next material. Parent material 1 is believed to be colluvium, which originated during or after loess deposition because it contains a large loess component. Henceforth, the uppermost parent material will be referred to as silty colluvium.

The middle portion of the solum (parent material 2) in each of the three pedons has mostly loam and clay loam textures (Table 1) in contrast to the silt loam textures of the silty colluvium, but it is differentiated from overlying and underlying materials by the high content of coarse fragments (Tables 1 and 2). The coarse fragment content is so high in some horizons of JF-3 and JF-4 (>60%, Table 1) that there is insufficient fine earth (< 2 mm) material to completely fill all the interstitial space between fragments. The coarse fragments exhibit random orientation indicative of colluvium. Sandstone constitutes essentially all of the coarse fragments, and sand contents in the fine earth fraction are correspondingly greater than in either superjacent or subjacent materials (Table 2). A stoneline occurs in pedon JF-4 at 81 cm, and constitutes the boundary between parent materials 2 and 3 in that pedon. The second parent material is believed to be colluvium consisting primarily of Waynesburg Sandstone.

The third parent material is identified as residuum (rock weathered in place) derived from Waynesburg Sandstone. All coarse fragments are sandstone and are oriented parallel and horizontally in contrast to the random orientation indicative of colluvium. Waynesburg No. 11 Coal [note the high organic carbon content (Table 2) and the dark color (Table 1)], Waynesburg No. 11 Coal Underclay, and Uniontown Shale [note the lack of structure (Table 1) and the high clay content (Table 2) for the latter two strata] underlie the Waynesburg Sandstone residuum in pedon JF-5. The Uniontown Shale is calcareous in contrast to the overlying acid materials (Table 2).

## Laboratory Studies

The recognition of lithologic discontinuities in soils is a prerequisite for making interpretations concerning pedogenic pathways. A first priority for the identification of discontinuities is field examination; field evidence is subsequently evaluated by laboratory techniques. Laboratory investigations used to test tentative identifications of lithologic discontinuities in the field included particle size distribution, elemental composition of the silt fraction, and clay mineralogy.

**Elemental Analysis.** Elemental analysis of sand and silt fractions have been employed previously by many scientists for the identification of lithologic discontinuities. Depth functions of elements or ratios of elements, such as Ti and Zr, that are found almost exclusively in minerals resistant to weathering are most commonly used to evaluate parent material uniformity. Although the range in Ti contents among the three soils is narrow (0.63 to 0.86%, Table 3), Ti is distinctly lowest in the silty colluvium, highest in the colluvium, and intermediate in the residua of all three pedons. The minimal difference between the colluvium (material 2) and residuum (material 3) is not surprising because both are derived primarily from Waynesburg Sandstone. The 15 to 20% lower Ti content of the silty colluvium compared to the underlying colluvium can be attributed to a lower Ti content in the loess component of the silty colluvium. Ti contents clearly support the identification of three materials. Zr contents show little variation within or among the soils (Table 3). Although Zr content of the silty colluvium tends to be slightly higher than the underlying colluvium, these parent materials are essentially indistinguishable using Zr content (range 0.06 to 0.08%). The residuum, however, consistently contains less Zr than the two overlying materials. Whereas Ti contents differentiate the upper two

Table 3
*Contents and ratios of elements occurring in resistant minerals in the total silt (2 - 50 μm) fractions of horizons selected to represent the various parent materials.*

| | JF-3 | | | | JF-4 | | | | JF-5 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parent Material | Horizon | % Ti | % Zr | Ti/Zr | Horizon | % Ti | % Zr | Ti/Zr | Horizon | % Ti | % Zr | Ti/Zr |
| Silty Colluvium | Ap2 | 0.71 | 0.08 | 8.8 | BE | 0.72 | 0.08 | 9.0 | BE | 0.63 | 0.07 | 9.0 |
| | Bt1 | 0.70 | 0.07 | 10.0 | Bt1 | 0.74 | 0.08 | 9.3 | Bt2 | 0.64 | 0.07 | [illegible] |
| | (Avg) | | | (9.4) | (Avg) | | | (9.2) | (Avg) | | | (9.1) |
| Colluvium | 2Bt4 | 0.80 | 0.07 | 11.4 | 2Bt3 | 0.86 | 0.07 | 12.3 | 2Btx2 | 0.75 | 0.06 | 12.5 |
| | 2Bt5 | 0.86 | 0.08 | 10.8 | 2Bt4 | 0.84 | 0.07 | 12.0 | 2Btx3 | 0.78 | 0.07 | 11.1 |
| | (Avg) | | | (11.1) | (Avg) | | | (12.2) | (Avg) | | | (11.8) |
| Residuum (Waynesburg Sandstone) | 3Bt6 | 0.81 | 0.05 | 16.2 | 3Bt6 | 0.80 | 0.06 | 13.3 | 3C1 | 0.75 | 0.05 | 15.0 |
| | 3BC2 | 0.77 | 0.06 | 12.8 | 3BC | 0.78 | 0.06 | 13.0 | | | | |
| | 3BC2 | 0.75 | 0.05 | 15.0 | | | | | | | | |
| | (Avg) | | | (14.6) | (Avg) | | | (13.2) | | | | (15.0) |
| Residuum (Waynesburg No. 11 Coal Underclay) | | | | | | | | | 5C3 | 0.73 | 0.06 | 12.2 |
| Residuum (Uniontown Shale) | | | | | | | | | 6C5 | 0.69 | 0.04 | 17.3 |

materials, Zr contents tend to differentiate the residuum.

Ti/Zr ratios are more reliable indices of parent material uniformity than either Ti or Zr because depth functions of ratios are not influenced by concentration or dilution caused by weathering phenomena (Smeck and Wilding 1980). Ranges of Ti/Zr ratios in parent materials 1, 2, and 3 are 8.8 to 10.0, 10.8 to 12.5, and 12.8 to 16.2%, respectively (Table 3). The percentage differences among Ti/Zr average ratios calculated for the various materials within each soil are sufficient to substantiate the lithologic discontinuities using criteria recommended by Drees and Wilding (1973). Not only can Ti/Zr ratios distinguish at least three parent materials in each soil, but the Ti/Zr ratios within a given parent material are very similar among the three soils. This is expected because the silty colluvium and colluvium seem to uniformly mantle the entire hillslope. The Waynesburg Sandstone, Waynesburg No. 11 Coal Underclay, and Uniontown Shale are also adequately differentiated with Ti/Zr ratios.

Elemental K content and K/Zr ratios of the silt fraction are lowest in the silty colluvium and highest in the residuum of each soil (Table 4). Elemental Ca content and Ca/Zr ratios do not show any definitive trends among the materials, except that the Ca/Zr ratios of the residuum tend to be greater than those of the overlying materials (Table 4). Fluctuations in the depth distribution of elements such as K and Ca that are common to weatherable minerals can be indicative of not only changes in lithology but also weathering differences. Because lithologic breaks have been established by ratios of elements in resistant minerals, contents and ratios of elements associated with weatherable minerals can only be used to assess degrees of weathering within any given parent material. Elements in weatherable minerals expressed as a ratio with elements in resistant minerals (such as K/Zr and Ca/Zr) are commonly referred to as weathering indices. Ca/Zr and K/Zr weathering indices suggest that all three parent materials are weathered to similar extents along the hillslope.

**CLAY MINERALOGY.** Clay mineralogy has been widely used in pedological investigations as an indicator of weathering intensity and, to a lesser extent, lithology. The colloidal clay fraction is a highly reactive material, and thus is relatively sensitive to processes active in the soil environment. Semi-quantitative estimates of the clay (<2 μm) mineralogical composition of pedons JF-3, JF-4, and JF-5 are perhaps most remarkable for their similarity (Table 5). In each case, the mineralogy is dominated by clay mica (illite), interstratified clay mica-vermiculite-smectite, and kaolinite in association with small quantities of quartz and iron oxides.

In the upper horizons of all three soils, expandable clay minerals (vermiculite and smectite) are heavily interlayered with hydroxy-A1 polymers derived from acid weathering of both the host and associated minerals. Whereas all other clay minerals may be found in both geologic and pedologic environments, hydroxy-A1 interlayered minerals (HIM) appear to be uniquely pedogenic. Thus, the content of HIM generally decreases with depth in weathering profiles. In the present study, the contents of HIM decrease rather uniformly with depth in pedons JF-3 and JF-4 (Table 5), despite vertical differences in parent material. Such distributions clearly demonstrate that weathering processes tend to attenuate lithological differences that might exist at the onset of soil formation.

Substantial quantities of kaolinite are present in all three soils. Kaolinite is also a common product of pedogenesis, especially under intense weathering regimes. In the present case, kaolinite contents do not systematically decrease with depth, thereby suggesting that the

TABLE 4

*Contents and ratios of elements occurring in weatherable minerals in the total silt (2 - 50 μm) fractions of horizons selected to represent the various parent materials.*

| | JF-3 | | | | | JF-4 | | | | | JF-5 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parent Material | Horizon | % K | % Ca | K/Zr | Ca/Zr | Horizon | % K | % Ca | K/Zr | Ca/Zr | Horizon | % K | % Ca | K/Zr | Ca/Zr |
| Silty Colluvium | Ap2 | 1.93 | 0.33 | 24.1 | 4.1 | BE | 1.98 | 0.33 | 24.8 | 4.1 | BE | 2.10 | 0.28 | 30.0 | 4.0 |
| | Bt1 | 2.32 | 0.20 | 33.1 | 2.9 | Bt1 | 2.13 | 0.25 | 26.6 | 3.1 | Bt2 | 2.24 | 0.24 | 32.0 | 3.4 |
| | (Avg) | | | (28.6) | (3.5) | (Avg) | | | (25.7) | (3.6) | (Avg) | | | (31.0) | (3.7) |
| Colluvium | 2Bt4 | 2.83 | 0.22 | 40.4 | 2.9 | 2Bt3 | 2.65 | 0.26 | 37.9 | 3.7 | 2Btx2 | 2.76 | 0.17 | 46.0 | 2.8 |
| | 2Bt5 | 2.94 | 0.21 | 36.8 | 2.6 | 2Bt4 | 2.86 | 0.29 | 40.9 | 4.1 | 2Btx3 | 2.73 | 0.19 | 39.0 | 2.7 |
| | (Avg) | | | (38.6) | (2.8) | (Avg) | | | (39.4) | (3.9) | (Avg) | | | (42.5) | (2.8) |
| Residuum (Waynesburg Sandstone) | 3Bt6 | 3.20 | 0.34 | 64.0 | 6.8 | 3Bt6 | 3.00 | 0.30 | 50.0 | 5.0 | 3C1 | 3.01 | 0.27 | 60.2 | 5.4 |
| | 3BC2 | 2.78 | 0.41 | 46.3 | 6.8 | 3BC | 3.02 | 0.26 | 50.3 | 4.3 | | | | | |
| | 3BC2 | 2.81 | 0.37 | 56.2 | 7.4 | | | | | | | | | | |
| | (Avg) | | | (55.5) | (7.0) | (Avg) | | | (50.2) | (4.7) | | | | (60.2) | (5.4) |
| Residuum (Waynesburg No. 11 Coal Underclay) | | | | | | | | | | | 5C3 | 1.94 | 0.59 | 32.3 | 9.8 |
| Residuum (Uniontown Shale) | | | | | | | | | | | 6C5 | 3.09 | 0.64 | 77.3 | 16.0 |

TABLE 5
*Estimated Clay (<2 μm) Mineralogy for Pedons JF-3, JF-4, and JF-5.*

| Horizon | Depth (cm) | Clay Mica | INT* | Vermiculite | HIM** | Kaolinite | Quartz | Fe-oxides |
|---|---|---|---|---|---|---|---|---|
| | | | | JF-3 | | | | |
| Ap2 | 8- 20 | XX | | | XXXX | XX | X | X |
| Bt1 | 25- 43 | XX | | XX | XXX | XX | X | X |
| 2Bt4 | 66- 81 | XX | XX | XX | XX | XXX | | X |
| 2Bt5 | 81- 91 | XXX | XX | XXX | X | XXX | | X |
| 2Bt6 | 91-112 | XXX | XXX | XX | | XX | | X |
| 3BC2 | 147-170 | XXX | XX | XXX | | X | | XX |
| 3BC2 | 170-196 | XXX | XX | XXX | | X | | XX |
| | | | | JF-4 | | | | |
| BE | 18- 25 | XX | | | XXXX | XX | X | X |
| Bt1 | 25- 38 | XXX | | | XXXX | XX | X | X |
| 2Bt3 | 51- 69 | XXX | | | XXX | XX | | X |
| 2Bt4 | 69- 81 | XXX | XX | XX | X | XXX | X | X |
| 3Bt6 | 107-140 | XXX | XX | XX | XX | XX | | X |
| 3BC | 157-179 | XXX | XXX | X | X | XXX | | X |
| | | | | JF-5 | | | | |
| BE | 20- 25 | XX | | | XXXX | XX | X | X |
| Bt2 | 36- 51 | XXX | XXX | | X | XX | | X |
| 2Btx2 | 69- 86 | XXX | XXX | | | XXX | | X |
| 2Btx3 | 86-109 | XXX | XXX | | | XXX | | X |
| 3C1 | 109-130 | XXX | XXX | | | XXX | | X |
| 5C3 | 147-163 | XXX | XXXX | | | X | | X |
| 6C5 | 183-208 | XXX | XXXX | | | XX | | X |

Mineralogy estimated from x-ray diffraction peak areas; X = <5%, XX = 5-25%, XXX = 25-50%, XXXX = 75%.

* INT = Interstratified clay-mica-vermiculite-smectite.

** HIM = hydroxy-A1 interlayered minerals (vermiculite + smectite).

mineral is largely inherited from the parent material(s) or that all three parent materials have been subjected to similar weathering regimes.

Clay mica is a common constituent of many temperate region soils and is abundant throughout pedons JF-3, JF-4, and JF-5. In leaching profiles, clay mica usually alters to vermiculite and/or smectite. The alteration process commonly involves transitory phases in which clay mica, vermiculite, and smectite layers become randomly interstratified. The appearance of vermiculite and/or interstratified phases at depth in the soils under investigation suggest that these minerals were originally present in all three parent materials and/or were formed during periods of soil formation prior to subsequent additions of colluvium. The apparent absence of these materials in surface and near-surface horizons is presumably caused by movement of A1 into expandable interlayers with subsequent formation of HIM.

Whereas differences in clay mineralogy between pedons JF-3, JF-4, and JF-5 are by no means pronounced, the lower contents of HIM and the abundance of interstratified mica-vermiculite-smectite in pedon JF-5 suggest a less intense weathering regime than in pedons JF-3 and JF-4. Weathering in this soil may be attenuated because of landscape position (constant accretion of material from upslope) and somewhat restricted internal drainage because of the fragipan. Clay mineralogy cannot be effectively utilized to distinguish lithological variations in these soils.

**PARTICLE SIZE DISTRIBUTION.** Clay content and distribution is not particularly useful for identifying lithologic discontinuities because these properties are highly influenced by pedogenesis, especially clay eluviation-illuviation (lessivage). Soil Taxonomy (Soil Survey Staff 1975) refers to pedogenic clay accumulations (as opposed to geologic concentrations) as argillic horizons. Clay films which provide direct evidence for lessivage and argillic horizon formation were noted in the present study in all three soils (Table 1). As illustrated in Figure 2, all pedons show evidence for multiple clay bulges, with maxima occurring in parent materials 1 and 3 in JF-3 and JF-4 and in 1 and 2 in JF-5. The occurrence of clay films in these zones of clay accumulation strongly suggests that it results from lessivage, wherein clays are translocated downward. Although the clay distribution does not provide any evidence for clay accumulation in the colluvium of JF-3 and JF-4, the occurrence of clay films (Table 1) suggests that clay has accumulated in the colluvium as a result of lessivage. The clay maxima in the Uniontown Shale in JF-5 is not pedogenic as there are no clay films; the high clay content below 147 cm in JF-5 is a characteristic of the parent materials.

The multiple pedogenic clay accumulations in all three soils provides strong evidence that the soils have been subjected to multiple periods of soil formation. On the other hand, evidence is apparent (Figure 2) for the removal of the upper portion of the argillic horizon and the overlying eluvial horizons in pedons JF-3 and JF-4 before deposition of the colluvium. A stoneline between the colluvium and residuum in JF-4 provides supporting evidence for truncation of the residual soil prior to addition of the colluvium. Furthermore, the absence of any evident soil development in the residuum of JF-5 may indicate that the entire residual soil was removed at this site during an erosional phase. Clay distribution strongly suggests that the hillslope has been subjected to alternating periods of erosion and stability.

## DISCUSSION

Field evidence and laboratory data presented have firmly established that the soils formed in three parent materials—residuum, colluvium, and silty colluvium. The occurrence of multiple pedogenic clay accumulations indicates that the three parent materials were deposited sequentially with intervening periods of soil formation. The following scenario is suggested: soils with a pronounced argillic horizon formed in the residuum; erosion truncated the residual soils; colluvium was deposited over the truncated residual soils; soils with weak argillic horizons formed in the colluvium; the colluvial soils were truncated by erosion; silty colluvium was deposited over the truncated colluvial soils; and a soil with a moderate argillic horizon formed at the present land surface. It should be noted that all three parent materials have been continually within the pedogenic active zone; thus, soil-forming processes have been and are currently active through all three materials.

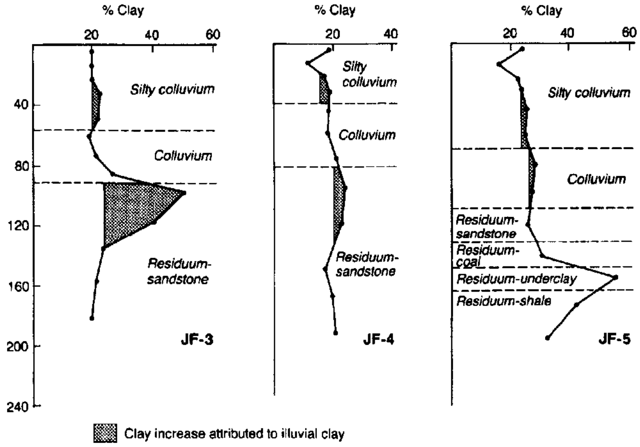


FIGURE 2. Total clay (< 2 μm) distributions in pedons JF-3, JF-4, and JF-5.

Clay mineral weathering and argillic horizon development in each parent material suggest that following deposition, each parent material was subjected to pedogenic processes during a period of landscape stability. Rust (1983) suggests that at least a thousand years are necessary to yield a clear expression of an argillic horizon. Since deposition of the silty colluvium, the slope studied has been stable because soil formation has progressed at a rate greater than downwearing by erosion. Ciolkosz et al. (1986) indicate that colluvial slopes in Pennsylvania may currently be in a "super stable" condition. They indicate that the present angle of repose of the colluvial slopes is less than that possible under the current climate because the angle of repose has been inherited from periglacial times. Ciolkosz et al. (1986) further indicate that periglacial features extend 160 km south of the ice margin and speculate that the occurrence of thick, well-developed soils south of the periglacial environment boundary and thin, less well-developed soils north of the boundary can be attributed to periglacial erosion.

Recently, Clark and Ciolkosz (1988) reviewed and summarized the evidence for periglacial activities in the Appalachian region south of the glacial border. They cite widespread evidence of periglacial features, with sideslope colluvial deposits being the most extensive. The periglacial environment during the Wisconsinan time provided conditions favorable for the formation of colluvium. Repetitive freeze-thaw cycles provide ideal conditions for solifluction. Furthermore, Clark and Ciolkosz (1988) indicate that the periglacial realm was possibly of a bi- or tripartite nature. Such a concept agrees with the evidence generated in the present study regarding the episodic nature of soil formation and solifluction events. Based on the degree of soil development, the loess component of the most recent colluvial deposit (silty colluvium) is believed to be of Late Wisconsin-age. Therefore, it is suggested that the episodes of landscape stability (soil formation) and instability (solifluction) were associated with the periglacial environment of the Wisconsinan glacial epoch.

ACKNOWLEDGMENTS. Salaries and research support provided by state and federal funds appropriated to the Ohio Agricultural Research and Development Center, The Ohio State University. Manuscript No. 237-89.

## LITERATURE CITED

Allison, L. E., W. B. Bolen, and C. D. Moodie 1965 Total carbon. *In*: C. A. Black (ed.) Methods of Soil Analysis. Am. Soc. of Agron., Madison, WI. p. 1346-1366.

Brewer, R. 1964 Fabric and Mineral Analysis of Soils. Wiley, New York, NY. 470 p.

Ciolkosz, E. J., R. C. Cronce, and W. D. Sevon 1986 Periglacial features in Pennsylvania. Agron. Series No. 92, College of Agriculture, Penn. State Univ., University Park, PA.

Clark, G. M. and E. J. Ciolkosz 1988 Periglacial geomorphology of the Appalachian Highlands and Interior Highlands south of the glacial border - A Review. Geomorphology 1: 191-220.

Drees, L. R. and L. P. Wilding 1973 Elemental variability within a sampling unit. Soil Sci. Soc. Am. Proc. 37: 82-87.

Dreimanis, A. 1962 Quantitative gasometric determination of calcite and dolomite by using the Chittick Apparatus. J. Sed. Pet. 32: 520-529.

Kilmer, V. J. and L. T. Alexander 1949 Methods of making mechanical analysis of soils. Soil Sci. 68: 15-24.

Lessig, H. D. 1959a Buried soils of Globe Hill, upper Ohio Valley. Ohio J. Sci. 59: 48-54.

——— 1959b Soil and paleosol of the Warnock Terrace. Ohio J. Sci. 59: 76-80.

——— 1959c The Supermarket Terrace, near East Liverpool, Ohio. Ohio J. Sci. 59: 332-338.

——— 1961a Soils of the high terrace remnants in the upper Ohio Valley. Ohio J. Sci. 61: 25-37.

——— 1961b The soils developed on Wisconsin and Illinoian-age glacial outwash terraces along Little Beaver Creek and the adjoining upper Ohio Valley, Columbiana County, Ohio. Ohio J. Sci. 61: 286-294.

——— 1963 The Calcutta Silt, a very early Pleistocene deposit in the upper Ohio Valley. Geol. Soc. Am. Bull. 74: 129-140.

——— 1964 Soils and their parent geologic materials in part of the unglaciated Allegheny Plateau, upper Ohio Valley, as interpreted from a pipeline excavation. Ohio J. Sci. 64: 385-400.

Peech, M., L. T. Alexander, L. A. Dean, and J. F. Reed 1947 Methods of soil analyses for soil fertility investigations. Agric. Handb. No. 757, U. S. Govern. Printing Office, Washington, DC.

Rust, R. H. 1983 Alfisols <u>In</u>: L. P. Wilding, N. E. Smeck, and G. F. Hall (ed.) Pedogenesis and Soil Taxonomy II. The Soil Orders. Elsevier, Amsterdam. p. 253-281.

Rutledge, E. M., N. Holowaychuk, G. F. Hall, and L. P. Wilding 1975a Loess in Ohio in relation to several possible source areas: I. Physical and Chemical Properties. Soil Soc. Am. Proc. 39: 1125-1132.

———, L. P. Wilding, G. F. Hall, and N. Holowaychuk 1975b Loess in Ohio in relation to several possible source areas: II. Elemental and mineralogical composition. Soil Sci. Soc. Am. Proc. 39: 1133-1139.

Shipitalo, M. J., N. E. Smeck, and J. M. Bigham 1988 Influence of underlying material on the weathering of loess in Ohio. Soil Sci. 146: 92-101.

Smeck, N. E. and L. P. Wilding 1980 Quantitative evaluation of pedon formation in calcareous glacial deposits in Ohio, USA. Geoderma 24: 1-16.

Soil Survey Staff 1984 Soil Survey Manual. USDA - Soil Conservation Service. Washington, DC.

——— 1975 Soil Taxonomy. USDA Agric. Handb. No. 436, U.S. Govern. Printing Office, Washington, DC.

Thompson, M. L., N. E. Smeck, and J. M. Bigham 1981 Parent materials and paleosols in the Teays River Valley, Ohio. Soil Sci. Soc. Am. J. 45: 918-925.